SECTION 3

MANAGEMENT PRACTICES FOR MINING WASTES

3.1 OVERVIEW OF THE MINING WASTE MANAGEMENT PROCESS

Mine waste, tailings, heap and dump leach waste, and mine water can be managed in a variety of ways. Figure 3-1 provides an overview of the mining waste management process. As shown in the figure, mine waste may be used on or off site, disposed of in mine waste piles, or used in leach operations to recover additional valuable constituents from the ore. Similarly, tailings may be used on or off site, disposed of in tailings ponds[1], or used in leach operations to recover valuable constituents in the tailings that are still present after milling processes have been completed. Tailings also may contain residues of the reagents used in flotation processes. These reagents include forms of cyanide (used in the leaching of gold and silver and in the separation of sulfide minerals), sulfuric acid used and formed in copper dump leaching, and various organic and inorganic compounds used in copper, lead and zinc flotation.[2]

Mine water may be discharged to surface streams (often after treatment) via National Pollutant Discharge Elimination System (NPDES) permitted outfalls, used as milling process makeup water (recycled), or used on site for other purposes (e.g., dust control, drilling fluids, sluicing solids back to the mine as backfill, etc.).

The recovery of valuable constituents from mine water (e.g., Ix treatment for uranium), from mill process solids, or from extraction from dump leach liquors could possibly be considered to be waste treatment processes, in that

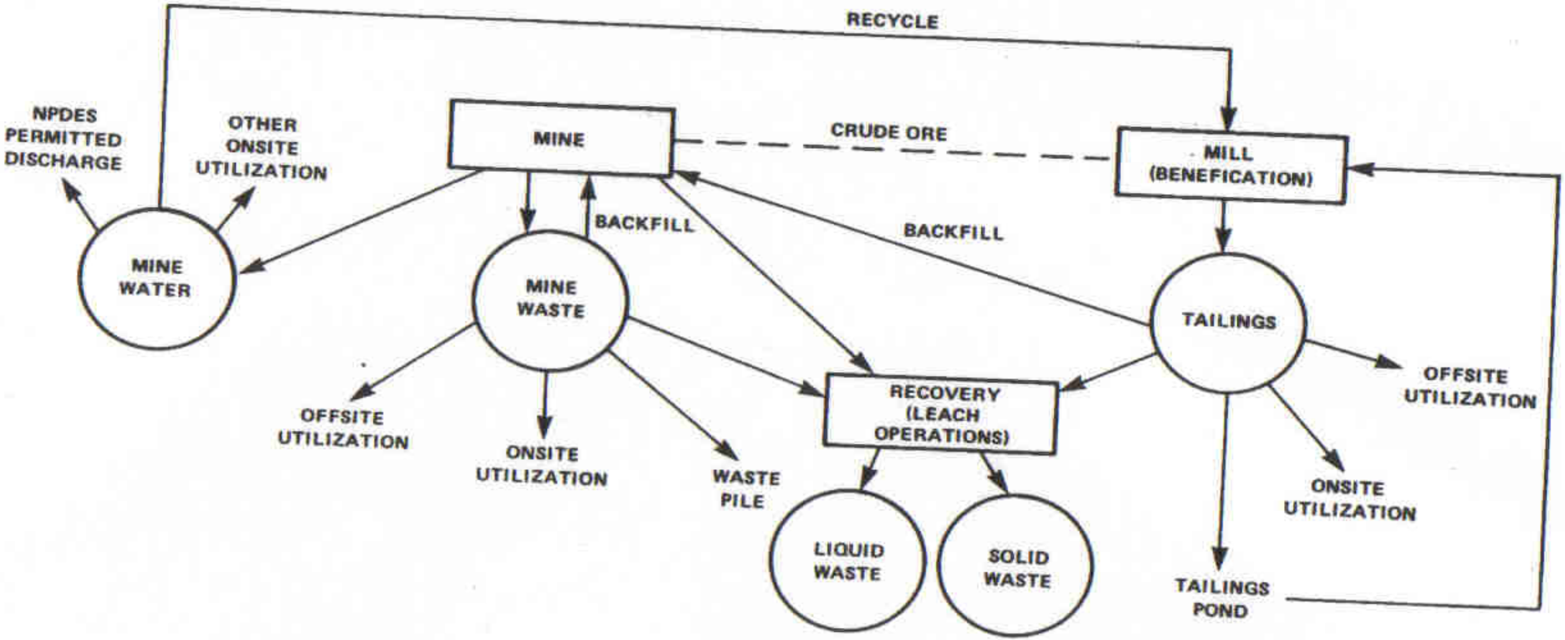


Figure 3-1 The mining waste management process

such recovery extracts metals or constituents that would otherwise be potentially hazardous or constituents of waste prior to disposal. However, the mining industry considers these processes to be extraction or beneficiation processes because they recover valuable products from materials that have metal concentrations below those in ore of a grade suitable or economical for milling and smelting.

Table 3-1 presents the volumes and percentages of mine waste and tailings that are currently managed according to the various practices shown in Figure 3-1 and mentioned above. The table shows that more than half of all mine waste and tailings is disposed of in poles and ponds, respectively. [3]
Most onsite utilization of mine waste and tailings involves the dump leaching of copper mine waste and the use of sand tailings to build tailings impoundment dams in all industry segments.

The remainder of this section is divided into three parts. Section 3.2 describes waste management practices other than actual disposal. The section includes a discussion of recovery operations, process changes for waste volume reduction, waste treatment methods, onsite utilization of mine water, and offsite use of mine waste and mill tailings. It shows that although several alternatives to onsite land disposal of mining industry wastes are available, their effectiveness in reducing the amount of mining industry wastes is limited.

Section 3.3 describes some general considerations for locating waste disposal sites and specific aspects of waste disposal for tailings, mine waste, leached material, and mine water.

Section 3.4 examines the measures that can be used to limit or mitigate the hazards posed by mining industry wastes that are disposed of on site.

Table 3-1 Current Waste Management Practices

Waste type	Management practice	Volume (in millions of metric tons per year)	Percent of waste generated
Mine waste	Pile	569	56
	Onsite utilization	313[a]	31
	Backfill	86	9
	Offsite utilization	43	4
	Total	1,011	100
Tailings	Ponds	267	61
	Onsite utilization	141[b]	32
	Backfill	21	5
	Offsite utilization	8[c]	2
	Total	437	100

a Includes dump 1 each operations and starter dams for tailings impoundments.

b Includes the sand fraction used in building tailings impoundment dams.

c Includes 4 million metric tons of Tennessee zinc tailings sold as construction materials or soil supplements.

Source: Charles River Associates 1984a, based on U.S. Bureau of Mines data.

These measures are particularly important because most of the large volume of mining industry wastes will ultimately remain on or near the site. The mitigative measures considered are broadly categorized under inspection and detection measures, liquid control systems, and corrective action measures.

3.2 WASTE MANAGEMENT PRACTICES

Waste management practices include process modifications for waste or potential hazard minimization, recovery operations, treatment prior to land disposal, onsite use of mine water, and offsite use of mine waste and mill tailings. Each of these practices is discussed below.

3.2.1 Process Modifications for Waste Minimization

Although there are no practical means of reducing the volume of solid waste produced by mining and beneficiation operations, some changes in beneficiation processes can lead to changes in the chemical composition of the tailings released into tailings impoundments. For example, pilot studies have been conducted in which nontoxic reagents were substituted for cyanide compounds in the beneficiation of copper ores. Sodium sulfide and sodium bisulfide may be used as alternatives to sodium cyanide (see 47 FR 25693, June 14, 1982). Similarly, alkalinity in the beneficiation circuits can be maintained by reagents less toxic than ammonia. Lime is the reagent of choice in most instances, although some scaling has been reported.

Two copper mills have circuits separating pyritic material from sulfide ores to improve subsequent copper recovery. The pyrites are currently discharged to the tailings impoundments, but they could be segregated. If pyrites were not codisposed of with other gangue material, there would be a reduction in the potential for acid formation after closure of the tailings impoundment. However, the alkaline tailings and pond water may act to reduce this potential.

The thickened discharge method of tailings management involves partially dewatering the tailings slurry and discharging it from a single point. This results in a gently sloping, cone-shaped deposit. The water removed from the tailings can be treated and discharged or returned to the milling circuit. The dewatering costs associated with this method are offset by reduced earthwork costs. A disadvantage of the thickened discharge technique in some circumstances is that no water is stored with the tailings, which may mean that the dewatered slurry piles become sources of fugitive dust. The particle size distribution of the waste and the drying characteristics of the disposal area are important factors in determining the potential for fugitive dust emissions. Earthquake activity may also affect the stability of the dewatered slurry piles, depending on the location. The thickened discharge method is currently used to dispose of sand tailings in the Florida phosphate industry segment, and could be applied to other sectors.[4,5]

Biological acid leaching, a new process under development in Canada, may be a feasible substitute for current dump leaching practices. Unlike dump leaching operations, the new process does not convert the sulfur in the ore to sulfuric acid; instead, it converts it to elemental sulfur, which is both less hazardous to the environment and potentially saleable. The process is still in the pilot development stage; the economic and technical feasibility of large-scale operations of this type have not yet been demonstrated.[6]

3.2.2 Recovery Operations

Leaching is a process used to recover metal values from low-grade ore or tailings, and is a colon practice in some mining segments (i.e., copper, gold, silver, and uranium). There are several types of leaching operations practiced, including in situ, dump, heap, and vat leaching. Acid solutions are commonly used for leaching in the copper segment of the mining industry.

Cyanide solutions are used to leach both gold and silver wastes as well as ores. The precious metals in cyanide leach solutions are removed in the process, and the partially spent cyanide solution is recycled back to the process for reuse. Leaching of phosphate rock and uranium wastes are also practiced.[7] In situ leaching in the uranium segment is practiced with water as the leach solution.

The purpose of using leaching techniques is to recover valuable metals from ores that would otherwise be uneconomical to mine. In situ and dump leaching techniques may cause environmental problems, in that an impermeable layer is not always placed or located between the low-grade ore and the surrounding soil, especially at older operations. However, it is in the miner's best interest to capture as much of the leachate in order to recover the metal values. The benefits of leaching are improved natural resource utilization and increased production of valuable metals such as gold, silver, and copper. The drawbacks of leaching, especially dump and in situ leaching, are that potentially corrosive (low-pH) or toxic (cyanide and/or toxic metals) products may seep into the ground below these operations. In ores that would naturally form acid drainage, leaching operations allow recovery of metals from ores that would naturally release these metals over a period of time.

In the copper, gold, and silver industries, technical efficiency and economic factors have made the recovery of mineral values by leaching processes economically feasible. Overburden, tailings, and other wastes will continue to be "remined" in the future, if extraction efficiencies continue to improve and if product prices exceed extraction costs.

Techniques other than leaching have been developed to recover valuable constituents from mine and mill wastes. Flotation can be used with copper mine waste, taconite (iron) tailings, and zinc mine waste.[8]

Pilot-scale research projects have also shown that it is technically feasible to use a high gradient magnetic separation process to produce an anorthosite concentrate, assaying at more than 28 percent alumina (Al_2O_3), from copper tailings. However, this has not proved economically competitive with alumina produced from bauxite by the Bayer process.[9]

3.2.3 Waste Treatment

Various oxidation systems have been developed to destroy cyanide compounds prior to discharge; however, most of the cyanide in cyanide leach processes is recycled back to the process for reuse. One system uses sodium hypochlorite and sodium hydroxide; another uses chlorine and sodium hydroxide.[10] Other processes have been used, including hydrogen peroxide oxidation, potassium permanganate, and chlorine dioxide. Destroying the cyanide used to leach metals may be feasible, using the new peroxide-thiosulfate process currently being developed by the Bureau of Mines IBOM).[11] In this method, hydrogen peroxide and sodium thiosulfate convert free and weakly complexed cyanide to thiocyanate. After the remaining complexed cyanide is precipitated and flocculated, the solution is filtered. Copper, iron, and other base metals associated with the gold and silver ore are removed along with the cyanide. However, thiocyanates have been shown to have latent toxic effects on fish; thiocyanate apparently accumulates in fish, only to be released in lethal form when the fish are stressed.[12]

Cyanide levels in froth flotation wastewater are generally low, and are the result of using cyanide to depress pyrites in the circuit. Ultraviolet radiation (from the sun) and simple aeration are often adequate to reduce the cyanide levels to detection levels.

Neutralization is a technically feasible method of treating corrosive acidic wastes. Chemical agents commonly used for this purpose include quicklime, limestone, hydrated or slaked lime, caustic soda, soda ash, and hydrated ammonia.[13]

The Effluent Limitations Guidelines and New Source Performance Standards for the ore mining and dressing point source category endorse the use of lime to maintain discharges within the 6.0 to 9.0 pH range. In fact, the permit issuer may allow the pH level in the final effluent to exceed 9.0 slightly, if that is required to meet discharge limitations for copper, lead, zinc, mercury, and cadmium.

Treatment of acidified mine waste or tailings is often a necessary prerequisite for revegetation. Hydrated lime or quicklime is used to increase the pH to 9.0 rapidly. For a slower but longer-lasting response, agricultural lime (limestone) is used. The lime is added in quantities great enough to neutralize the sulfuric acid that will be released by the future oxidation of pyritic material in the mine or mill waste.[14]

3.2.4 Onsite Use of Mine Water

Water generated by mine dewatering may be used in the milling process as makeup water (treatment may or may not be required), or used on site for dust control, sluicing solids to the mine as backfill or in cooling or drilling fluids. Depending on the water balance at a facility, managing the mine water may involve a combination of these uses. A large number of mining and beneficiation operations use mine water in the mill. In some cases, all of the water required by the mill operation is obtained from mine drainage, which eliminates the need for wells and a mine water treatment system, or greatly reduces the volume of mine water discharged. Using mine water containing relatively high concentrations of soluble metals for beneficiation makeup water is an effective treatment practice, because flotation circuits, which are typically alkaline, reduce the solubility of metals and thereby facilitate their recovery. In most cases, however, not all of the mine water is used in the beneficiating operations, because operators have little or no control over the quantity of water that infiltrates the mine. The unused portion of the mine water is generally stored in impoundments and discharged after treatment, in accordance with the provisions of an NPDES permit.[15]

3.2.5 Offsite Use of Mine Waste and Mill Tailings

Waste utilization practices include agricultural lime replacement, road and building construction, and the production of bricks, ceramics, and wallboard. These methods are discussed below and summarized in Table 3-2.

The most widespread use for these wastes is in the production of concrete and bituminous aggregates for road construction. Other applications in road construction include the use of these wastes in road bases, as embankments, and to make antiskid surfaces. Approximately 50 percent of the zinc tailings in Tennessee are sold for aggregate production.

Tennessee zinc tailings also may be used as a substitute for mortar or agricultural limestone; nearly 40 percent of these tailings are sold for these purposes. Tailings from mills processing zinc ores in New York and the Rocky Mountain states are not suitable as soil supplements, because these tailings have lower concentrations of calcium carbonate and higher concentrations of lead and cadmium. Similar concerns constrain the use of lead tailings in Missouri. [16]

Tailings from asbestos and molybdenum mining operations have been used in asphalt mixes for roads and parking lots. Phosphate, gold, and silver

Table 3-2 Uses of Mine Waste and Tailings

Use	Asbestos	Copper	Gold & silver	Iron ore/ taconite	Lead	Molybdenum	Phosphate	Uranium	Zinc
Material Use									
Soil Supplement									1
Wall Board Production	3								
Brick/Block Production	1	1	1	1					
Ceramic Products							1		
Anti-Skid Aggregate				3			1		
Embankments	3	3	3	3					
General Aggregate			3	3	3				
Fill or Pavement Base		3	3	3	3				
Asphalt Aggregate	2			3	3	3		1	3
Concrete Aggregate			3	3	3		1		3

<u>Development Stage</u>

1. Bench-scale research project
2. Full-scale demonstration project
3. Full-scale, sporadically practiced

Source: Based on Seitter and Hunt 1982.

tailings of sand and gravel size have been mixed with cement to form concrete for use in road construction. Lead, zinc, and iron ore tailings have been used for both concrete and bituminous aggregates. Mixtures of crushed waste rock, including waste material from copper, iron ore, lead, gold, and silver mines, have become embankments, fills, or pavement bases for many highways. Topsoil must be deposited over fills and embankments made with these materials to control erosion and permit the growth of vegetation. Taconite tailings have proved valuable as thin (less than 25 mm) road surface overlays, because they greatly enhance skid resistance.

The use of tailings to produce bricks, blocks, and ceramic products has not yet passed the bench-scale research stage. Copper mill tailings can be used in brick production if pyrites are first removed. Lightweight blocks made from taconite tailings have good structural characteristics but have not been marketed.

The most important constraints on the use of mining wastes are imposed by energy, economic, and logistic considerations. Material/metal recovery from mining wastes is economically attractive only when the price of the material recovered exceeds the costs of extraction. In recent years, mine product prices have been generally depressed, and extraction costs, especially energy-related costs, have risen. Similarly, using mining wastes to produce bricks or to construct roads is affected by such market constraints as transportation costs and competition with other sources located nearer to potential users.[17] Mining wastes, therefore, are competitive only when they can be marketed or used in the geographical area close to the originating mine.

Uses of mining wastes do not and will not keep pace with the approximately 1 to 2 billion metric tons of these wastes that may be generated each year. Long-term management of mining waste disposal sites will continue to be necessary for the foreseeable future. However, research on the cost-effective utilization of mining wastes is justified, because any new use that becomes widely practiced will help reduce the magnitude of the mining waste disposal problem.

3.3 WASTE SITING AND DISPOSAL METHODS

For technical and economic reasons, most mining waste is finally disposed of on the land. The primary considerations for locating a waste disposal area are discussed below. Specific waste disposal methods for mining wastes are also described.

3.3.1 Location and Siting

The topography, geography, and hydrogeology and, in some cases, meteorology, as well as population density of the geographical area in which a mine is located, affect the siting of the waste disposal area, the extent to which mitigative practices are required, and the types of mitigative systems that can be selected. The extent of the ore body, the quantity of waste to be generated, and the method of mining are also considered when siting a disposal area.

Owners and operators of mines built before 1970 generally located waste sites at the shortest and most easily traversed distance from the mine or mill, usually in a ravine or gully. Owners and operators of mines constructed since 1970 (when Federal and state environmental regulation greatly increased) have also considered the potential pollution problems associated with particular sites, such as siltation of surface waters, production of fugitive dust emissions, and contamination of ground water. Disposal locations chosen based on these considerations may have small upgradient drainage areas to reduce erosion potential, or may be underlain by impermeable strata to minimize percolation into ground water.

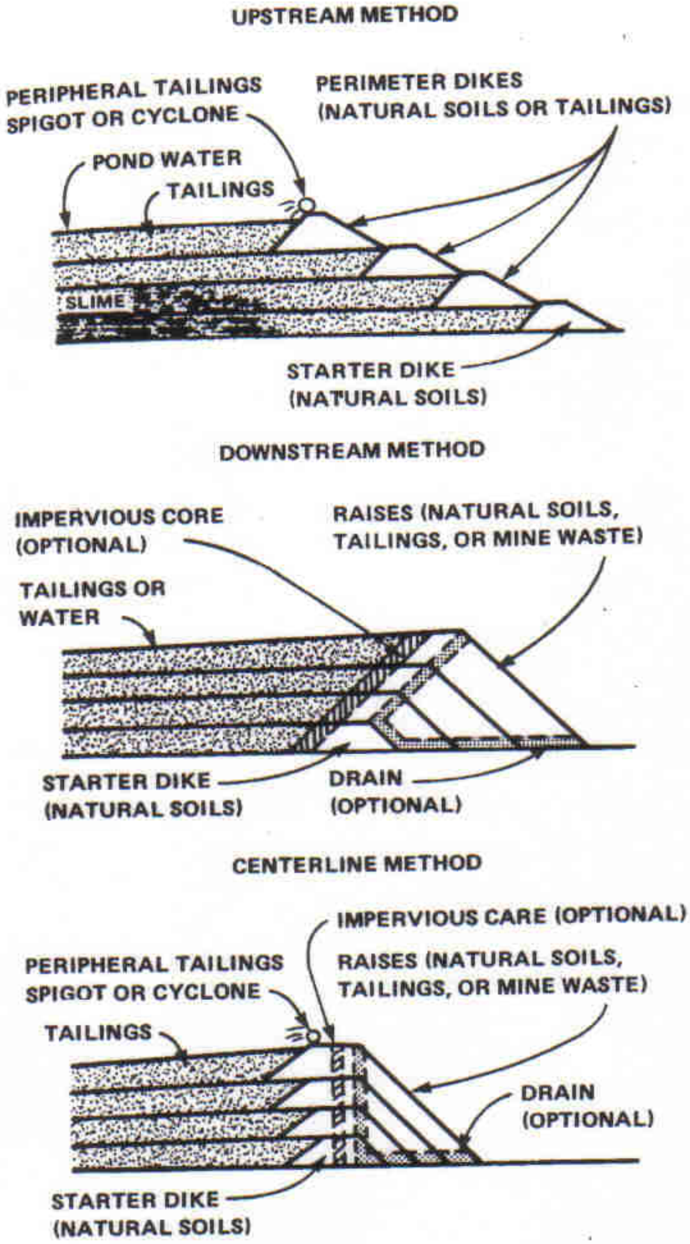
3.3.2 Waste Disposal Methods for Tailings

Waste disposal methods for tailings include: tailings ponds, stope[18] backfilling, below-grade disposal, and offshore disposal. As was shown in Table 3-1, more than half of the tailings are disposed of in tailings ponds. The size and design of the ponds vary widely by industry segment and location. Tailings disposal methods are discussed below.

(1) Tailings Impoundments. Tailings impoundments have been used at ore mills in the United States since the early 1900s. In recent years, they have become increasingly important and may account for as much as 20 percent of the construction cost of a mine/mill project.[19] Some ore bodies may not be exploited, because suitable sites for tailings disposal are not available within a practical distance.

Tailings impoundments may serve several purposes. They retain water, making it available for recycling to the mill flotation circuits and other processes requiring water. They act as equalization basins, which assist in wastewater treatment process control and reagent addition control. They also protect the quality of surface waterways by preventing the release of suspended solids and dissolved chemicals. In fact, tailings impoundments in arid regions may permit a mill to achieve "zero discharge," eliminating the need for a point source discharge permit.

The design and construction of a tailings impoundment reflect the characteristics of the ore, the mine/mill, and the environment, especially the local topography. Three methods of dam building are commonly used: downstream, upstream, and centerline. Figure 3-2 depicts these methods.



Source: Vick 1981

Figure 3-2 Tailings dam construction methods

A common element in all three types is that they are usually raised sequentially as the level of tailings and/or effluent in the impoundment rises, in order to distribute construction costs more evenly over the life of the facility.[20]

With the downstream construction method, the embankment building material is added successively to the downstream side of the previously placed embankment, and the crest thus moves downstream. This system is costly but is compatible with any type of tailings and can be used for water storage. The upstream method is less costly but is not well suited to large inflows and water storage. The centerline method involves raising the dam in steps, with the centerline of the crest remaining above the starter dam.[21]

The starter dam or dike is typically built with natural soils, but mine waste can also be used. Subsequent increments are added from the coarse, sandy fraction of the tailings. This use of tailings constitutes the largest component of the 141 million metric tons of onsite utilization of tailings shown in Table 3-1. Installation of internal filters and drains lowers the water level within the sand dam and reduces the danger of overtopping, instability, or breaks induced by seismic (earthquake) activity.[22] Other protective measures include reduction of the catchment area by maintaining diversion ditches around the impoundment and careful control of water inflow and outflow to allow for seasonal and mill operation variations.[23] In summary, many tailings ponds and impoundments require some degree of seepage to maintain their structural integrity.

Upstream embankments are widely used by the copper industry in the southwest. Earthquake activity and high precipitation along the West Coast have fostered use of downstream and centerline dams. Downstream dams are also favored by the lead industry in Missouri and the phosphate industry in Florida.

(2) Stope Backfilling. This method, also referred to as sandfilling, involves converting a portion of the coarse fraction of tailings into a slurry and then injecting the slurry into the mined-out portions of stopes. Stope backfilling is currently practiced or is being considered as a method of disposing of such diverse materials as copper tailings, spent shale from oil shale retorts, and tailings from Wyoming trona (sodium carbonate) mines.[24]

The major disadvantages of stope backfilling are the introduction of additional water into the mine, which results in occasional spills of tailings, and the importation of supplemental waste material to make tailings embankments when too much coarse fraction has been removed from the tailings. The primary drawback to backfilling with fines (materials with small particle sizes) is the risk of poor drainage of the backfill material. In addition, although no supporting monitoring data are available, backfilling of tailings into underground mines may have an adverse impact on ground-water quality. For example, metals or other constituents may leach from the coarse tailings and reach the ground water when seepage from the backfilled stopes occurs.[25] This possibility increases when the coarse tailings contain pyrites, which generate sulfuric acid that decreases pH and increases the solubility of most toxic metals.

Stope backfilling as a tailings management alternative is not used on a national scale, because most of the industry segments covered in this report excavate their ores using surface mining techniques.

(3) Below-Grade Disposal. This method of tailings disposal consists of placing tailings in an excavated pit (in lieu of above-grade impoundments) so that at closure, the entire deposit is below the level of the original land surface. This method currently is unique to the uranium industry, which uses

it to reduce the likelihood of erosion. The embankments of conventional above-grade surface impoundments are subject to erosion and failure that could result in the release of tailings to the downgradient area. Below-grade disposal avoids both of these potential problems. This disposal method is costly unless mined-out pits can be used.[26,27] This method could be used for operations involving open-pit mining if a series of mined-out pits is available to receive mill tailings (or retorted shale).

(4) Offshore Disposal. In the past, offshore disposal has been a euphemism for dumping tailings into a large lake or the ocean without regard for environmental consequences. Recently, more responsible proposals have shown that if the tailings are chemically innocuous, are sufficiently coarse to settle rapidly with a minimum amount of turbidity, and are piped to deep-water areas to avoid the most biologically productive nearshore zones, offshore disposal may have reasonably small environmental impacts in certain specific cases. Even so, offshore disposal is not a widely accepted alternative within regulatory agencies in the United States and Canada, and few mines have been located near the ocean in the past. Technical arguments notwithstanding, recent experience indicates that most developed countries will not approve offshore disposal of tailings.[28]

3.3.3 Waste Disposal Methods for Mine Waste

As was shown in Table 3-1, an estimated 56 percent of the mine waste removed to gain access to an ore body is disposed of in mine waste piles near or adjacent to the mine. The overburden from open pit mines is usually discarded on the outside slopes of the pit. Approximately 9 percent of the mine waste is disposed of as part of the normal mining practice of immediately backfilling previously excavated areas; the trend in the mining industry is toward increasing this percentage. In surface mining, however, backfilling is only used when the overburden can be placed into adjacent areas that have been excavated. With some underground mining methods, waste rock is backfilled into previously mined sections as it is excavated, which eliminates the time and expense of hauling the material to the surface for stockpiling. These mining methods include cut-and-fill stoping and square-set stoping. These methods provide structural stability to the mined areas, in addition to serving as a means of waste disposal. [29]

3.3.4 Waste Disposal Methods for Dump Leach/Heap Leach Material

Whether or not active dump leach and heap leach operations are considered to be process operations rather than solid waste disposal practices, solid waste material remains after the completion of these operations. The current practice is to transport overburden and low-grade copper ore for dump leach processes (or waste and low-grade precious metal ore for heap leach operations) to leaching beds, where the dumped material is spread by bulldozers. Equipment travel on the leach dump compacts the top layer of the material; this layer is then scarified to facilitate infiltration of the leach solution. This process of layering and subsequent scarifying of the leach dump may continue for 50 years or more.[30] The leached waste material is not removed from the site of the operation, due to the immense size of these piles.

3.3.5 Waste Disposal Methods for Mine Water

Water produced from mine dewatering may be discharged directly or indirectly (after treatment such as settling) to a surface stream, used in the milling process as makeup water (treatment may or may not be required), pumped to a tailings pond, or used on site for dust control, cooling, or as drilling fluids, etc. (see Section 3.2.4). Depending on the water balance of the particular mine facility, mine water management may involve one or a combination of these methods.

Treatment of mine water in onsite impoundments is the management practice used when discharge or total recycling are not possible. Such treatments include simple settling, precipitation, the addition of coagulants and flocculants, or the removal of certain species (e.g., radium-226 removal by coprecipitation with barium chloride in mine water ponds in the uranium industry). Most mine water ponds are relatively small, shallow, excavated, unlined impoundments. The number of impoundments and their size depends on the volume of mine water handled and the treatment methods used. Larger impoundments or several impoundments in series are used to provide sufficient retention time for effective treatment. Discharge from mine water treatment ponds is usually to a surface stream via an NPDES-permitted outfall. [31]

3.4 MITIGATIVE MEASURES FOR LAND DISPOSAL SITES

Even if greater use is made of waste utilization and alternative waste disposal methods, the greatest portion of mining wastes will still be disposed of in land disposal facilities such as waste piles, tailings ponds, and settling impoundments. However, various measures are available to detect or mitigate the problems associated with the land disposal of mining wastes. These measures may be classified into four general types:

1. Detection and inspection measures determine whether problems are developing. These activities include ground-water monitoring and visual inspection of other systems, erosion control, dam stability, and runoff control.

2. Liquid control measures control the potential for liquid to come into contact with mining waste, and thus minimize surface water pollution and the amount of liquid available for leachate formation.
3. Containment systems prevent leachate from entering the ground water and posing a threat to human health and the environment. Two types of containment systems are considered here: containment systems designed to prevent leachate from entering the ground water (such as liners and systems designed to control plumes of contaminated ground water) and corrective action measures.

4 4. Security systems prevent entry to the waste management area by animals or by unauthorized persons. These systems protect the general public and prevent activities that might damage onsite control systems.

The waste management measures that are most relevant to individual waste management sites depend, in part, on the operational phase of the waste management site. Three operational phases are distinguished here:

1. Active site life is the period during which waste is being added to the disposal site. A disposal site may be closed even though the mine itself remains active.
2. Closure is the period immediately following active site life, in which various activities are undertaken to ensure adequate protection of human health and the environment during the post-closure phase, and to minimize maintenance activities in the post-closure phase.
3. Post-closure is the period following closure during which there are no further additions of waste to the site. The main post-closure activities are the monitoring of the site for leaks and the

maintenance of liquid control, containment, and security systems established during site life or at the time of closure.

Corrective action occurs after a plume of contaminated ground water or another environmental hazard is discovered. This may occur during active site life, at the time of closure, or during the post-closure phase.

The remainder of this section describes various mitigative measures appropriate to the management of mining waste during the active life of the site, the closure period, and the post-closure phase, and discusses appropriate corrective measures. Some of the measures described can be substituted for each other. In most cases, the ability of these measures, or combinations of measures, to limit threats to human health and the environment depends on specific site conditions; in addition, many of these measures have yet to be applied in the mining waste context. The discussion below describes the purposes and limitations of various management techniques, but data are not available to allow the efficacy of these techniques to be quantified. Table 3-3 shows the various measures discussed in this section, classified by operational phase of the site.

Where possible, EPA has estimated the percentage of mines in some industry segments where the following mitigative measures are currently used: ground-water monitoring, run-on/runoff controls for storm water, liners for tailings ponds, secondary leachate collection and removal, and closure procedures. EPA produced these estimates using the methodology described in Appendix B.

3.4.1 Mitigative Measures During Active Site Life

During the active life of a waste disposal facility, waste is continually being added to the waste material already at the site. The ongoing nature of the disposal process at active sites makes certain mitigative measures

Table 3-3 Mitigative Measures by Stage of Site Life

Stage of site life	Mitigative measure	Purpose
Active site life	Hydrogeologic evaluation and ground-water monitoring	Detection of contaminants
	Run-on/runoff control	Liquid control
	Liners	Containment
	Cutoff walls	Containment
	Leachate collection, removal, and treatment systems	Liquid control
	Security systems	Security of control systems and protection of public health
Closure	Continue measures initiate during active site life	All purposes mentioned above
	Wastewater treatment	Liquid control
	Pond sediment removal	Waste removal
	Dike stabilization	Liquid control
	Waste stabilization	Liquid control
	Installation of leachate collection, removal and treatment systems at surface impoundments	Liquid control
	Final cover	Liquid control
Post-closure	Ground-water monitoring	Detection of contaminants
	Inspect/maintain all existing system	All purposes mentioned above
Corrective action		

Interceptor wells	Containment
Hydraulic barriers	Containment
Grouting	Containment
Cutoff walls	Containment
Collection	Treatment

Source: Meridian Research, Inc. 1985.

inappropriate for use at such sites. For example, methods such as caps or covers that are designed to control the volume of liquids percolating into the site cannot be used. Similarly, liners and containment systems that underlie the waste area can most easily be put in place at new facilities. However, other mitigative measures, such as those discussed below, can be used at existing active waste disposal sites.

3.4.1.1 Ground-Water Monitoring and Hydrogeological Evaluation

The objectives of hydrogeological evaluation and ground-water monitoring at a waste disposal or tailings pond facility are (1) to identify potential pathways of leakage and contaminant transport by ground water; (2) to determine whether contamination of the ground water has occurred and, if so, the extent of contamination; and (3) if necessary, to generate the data needed to select and implement a mitigative strategy. At new facilities, the first step in this process is to evaluate the pollution potential of effluents from the site. [32] A thorough hydrogeological evaluation and ground-water monitoring program are then conducted to characterize background or natural conditions at the site. In some cases, it may be necessary, prior to siting the monitoring wells, to simulate baseline and potential ground-water pathways by means of hydraulic or solute transport models.[33] Particularly in areas close to dams or dikes, hydrogeological evaluations are necessary to determine probable seepage paths and to establish flow rates to be used in the design of dikes, cutoff walls, and liners. Ground-water monitoring is also an important means of evaluating the initial and long-term effectiveness of the engineering and site preparation measures used at a particular site.

Depending on the specific characteristics and requirements of a given site, monitoring programs range in complexity from a simple determination of the presence or absence of a particular waste constituent in a few wells to an extensive analysis of many constituents in many wells, using well clusters open at different depths, aquifer tests, and geophysical measurements.[34,35] The complexity of an effective ground-water monitoring program is directly related to the size of the waste management project, the nature of the waste materials, and the characteristics of the local hydrogeology.

Using ground-water monitoring to assess conditions at a site has some limitations. Because a monitoring well characterizes only one point in an aquifer, results obtained at the well may not be representative of site conditions, especially in geologically complex areas. Another limitation of ground-water monitoring is that some knowledge of site conditions, such as ground-water flow rate and direction, is necessary before the monitoring wells can be placed properly. In addition, because ground-water flow is extremely slow, long-term monitoring over several months or years may be required to characterize the situation accurately. In some circumstances, the flow patterns of ground water through fractures may be sufficiently complex to frustrate even the most intensive monitoring effort. [36,37]

Waste disposal facilities in the mining industry are so large that horizontal and vertical distances between hydraulically upgradient, and therefore unimpacted, areas and areas that are downgradient, and therefore likely to be impacted, can be very great. The variation in natural conditions over such large distances (thousands of meters) can greatly complicate hydrogeological studies. In some cases, the presence of several active, inactive, or abandoned waste disposal sites or mines in the area also complicates ground-water quality and flow patterns, making ground-water monitoring and hydrogeologic evaluation more difficult. [38,39]

Nevertheless, hydrogeologic evaluation and ground-water monitoring remain the only methods for determining whether there is a danger of offsite movement of contamination from mining wastes. Because of the size and complexity of many mining waste sites, the need for detailed hydrogeologic evaluation and careful interpretation of ground-water monitoring results may be greater than for other types of hazardous waste management facilities.

Tables 3-4 and 3-5 show the extent to which ground-water monitoring, practiced voluntarily or in compliance with State regulations and adequate to satisfy current RCRA requirements, is performed at heap/dump leach operations and tailings ponds in the various mining industry segments. (Ground-water monitoring is not normally performed at mine waste disposal sites.) Ground-water monitoring of gold and silver heap leach operations adequate to satisfy current RCRA requirements is currently practiced at all of the gold and silver mine sites studied by EPA where there are heap leach operations. Ground-water monitoring adequate to satisfy RCRA requirements is currently practiced at two of the nine copper dump leach operations studied by EPA.

Monitoring of ground water is also practiced at all of the gold and silver tailings ponds and at 2 of the 12 copper tailings ponds studied by EPA. It is not performed at any of the lead or zinc tailings ponds studied by EPA.

3.4.1.2 Run-on/Runoff Controls

Run-on/runoff controls can be divided into three categories: diversion methods, containment systems, and runoff acceleration practices. Diversion systems prevent offsite water from entering the site and causing erosion and flooding. Containment involves the collection of onsite stormwater or dike seepage in holding or evaporation ponds for the treatment necessary for final disposal or to prepare the waste for recycling.

Table 3-4 Extent of Ground-Water Monitoring of Heap/Dump Leach Waste, by Industry Segment

Mining industry segment	Number of mine sites in data base that generate heap/dump leach waste	Number of mine sites that monitor ground water at heap/dump leach waste operations[a]	States requiring ground-water monitoring or having mine sites that monitor ground water at heap/dump leach waste operations[b,c]
Copper	9	2 (22%)	Arizona, New Mexico
Gold	5	5 (100%)	Montana, Nevada, Colorado, New Mexico, South Dakota
Silver	1	1 (100%)	Nevada

a Sites are identified as having ground-water monitoring only when such monitoring is adequate to satisfy current RCRA requirements.

b This column includes only those states where ground-water monitoring requirements are at least as stringent as required by RCRA.

c This column includes only the states generating large amounts of mining industry waste in the affected industry sectors.

Source: Charles River Associates 1984 and 1985c.

Table 3-5 Extent of Ground-Water Monitoring of Tailings Ponds, by Industry Segment

Mining industry segment	Number of mine sites in data that generate tailings	Number of mine sites that monitor ground water at tailings ponds[a]	States requiring ground-water monitoring or having mine sites that monitor ground water at tailings ponds[b,c]
Copper	12	2 (17%)	New Mexico, Colorado, California, Arizona
Gold	7	7 (100%)	Arizona, South Dakota, Nevada
Lead	6	0	
Phosphate	8	1 (13%)	Florida, North Carolina
Silver	8	8 (100%)	Montana, Idaho, Colorado, Utah
Zinc	6	0	

a Sites are identified as having ground-water monitoring only when such monitoring is adequate to satisfy current RCRA requirements.

b This column includes only those states where ground-water monitoring requirements are at least as stringent as required by RCRA.

c This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

Surface water diversion ditches consist of canals, channels, or pipes that totally or partially surround waste piles, tailings embankments, pits, or ponds to divert the surface water around them and back into the natural stream channel downgradient to the waste area. The most important functions of ditch systems are to minimize downstream environmental damage, relieve dike stresses to reduce the chance of failure, diminish erosion of the waste embankment, and reduce the volume of water requiring environmental monitoring.[40,41] Perimeter ditches also help to recover supernatant for recycling, collect and drain dike seepage, and collect onsite storm runoff for transport to a containment treatment system. When wastewater requires treatment before release, a suitable ditch network is constructed to prevent uncontaminated offsite or onsite runoff from mixing with onsite wastewater streams.

Table 3-6 shows the extent for which mine waste piles studied by EPA have run-on/runoff controls for storm water adequate to satisfy current RCRA requirements. Run-on controls for mine waste that are adequate to satisfy RCRA exist only at three mines studied by EPA in the gold industry sector. Runoff controls exist at these same three mines and at one silver mine in Colorado.

3.4.1.3 Liners

Lining the entire waste area and the upstream slope of the embankment may prevent seepage. Liners can be formed from natural earthen (clay) materials, synthetic materials, or a combination of these. Commercial bentonite can be added to fine-textured soils to reduce their permeability to very low levels. Synthetic liner materials include soil cements, treated bentonite, petroleum derivatives, plastics, elastomers, and rubber. These liners are generally more expensive than liners made of earthen materials, and careful earthwork is

Table 3-6 Extent of Run-on/Runoff Controls for Stormwater for Mine Waste, by Industry Segment

Mining industry segment	No. mines in data base that generate mine waste	No. mine sites with run-on controls[a]	No. mine sites with runoff controls[b]	States requiring run-on/ runoff controls or having mine sites with Run-on[c] controls	Runoff[c] controls
Copper	13	0	0		
Gold	11	3 (27%)	3 (27%)	Montana, California	Montana, California
Lead	7	0	0		
Phosphate	18	0	1		N. Carolina
Silver	9	0	1 (11%)		Colorado
Uranium	9	0	0		
Zinc	7	0	0		

a Sites are identified as having run-on controls only when these controls are adequate to satisfy current RCRA requirements.

b Sites are identified as having runoff controls only when these controls are adequate to satisfy current RCRA requirements.

c These columns include only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

required to prepare the ground surface even when these synthetic materials are used. If appropriate earthen liner materials are not readily available, synthetic liners may be more economical. Liner materials must be resistant to the potential corrosive effects of the waste and to damage from sunlight (if the liner is not covered immediately after placement). [42]

Although both synthetic and natural liners can be used cost-effectively in relatively small disposal areas, they have not been used in the very large waste facilities that are typical of mining industry waste sites (some of which cover a square kilometer or more); and they may in fact not be feasible at such sites. [43] Experience is inadequate to evaluate the performance of liners at large-area, large-volume sites. Lining large areas with synthetic (membrane-type) liners would require many liners to be fastened together to form a single large liner; each seam represents a point of potential failure. If a liner underlying such a large waste area failed, it would be impossible to repair. [44]

Installing liners at existing disposal areas in this industry would require moving billions of tons (approximately 50 billion tons) of material that has been deposited over the years. Many active disposal sites have been used for many years, and the areas are continually built up. Movement of these materials to new lined sites severely affects the cost of operations at these sites.

Table 3-7 shows the extent of the current use of tailings pond liners adequate to satisfy current RCRA requirements, for mines studied by EPA. Mine waste piles are not normally lined. According to Table 3-7, the majority of tailings ponds at mine sites studied by EPA in the silver and zinc industry segments are currently lined. Tailings ponds at mines studied by EPA in the

Table 3-7 Extent of Tailings Pond Liner Use, by Industry Segment

Mining industry segment	Number of mines in data base that use tailings pond liners	Number of mine sites having lined tailings ponds[a]	States requiring liners or having mine sites with lined tailings ponds[b,c]
Copper	12	0	
Gold	6	1 (17%)	Nevada
Lead	6	0	
Phosphate	18	0	
Silver	8	6 (75%)	Idaho, Utah
Zinc	6	4 (67%)	Tennessee

a Sites are identified as having lined tailings ponds only when the liner is adequate to satisfy current RCRA requirements.

b This column includes only those states where liner requirements are at least as stringent as those required by RCRA.

c This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

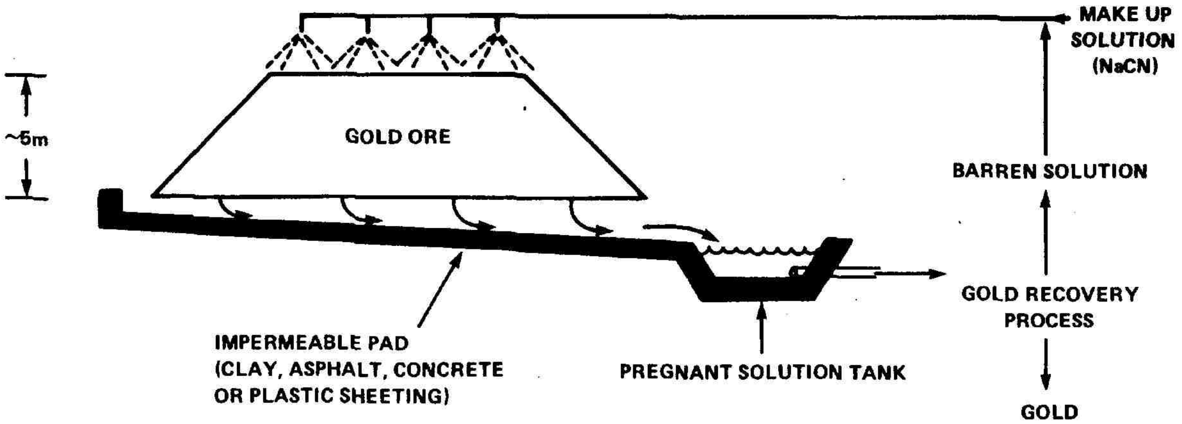
copper, lead, and phosphate industry segments are not lined. One of the six tailings ponds at mines studied by EPA in the gold industry segment is currently lined.

Regulations promulgated in 40 CFR Part 192 required that new uranium mill tailings impoundments be lined. Synthetic liners have been installed at three uranium mill tailings impoundments and natural liners exist at other uranium tailings impoundments.

Many mines studied by EPA have impermeable pads under heap leach piles. Figure 3-3 shows an impermeable pad under a gold heap leach pile. These pads aid in the collection of valuable leachate and reduce the pollution potential at these sites.

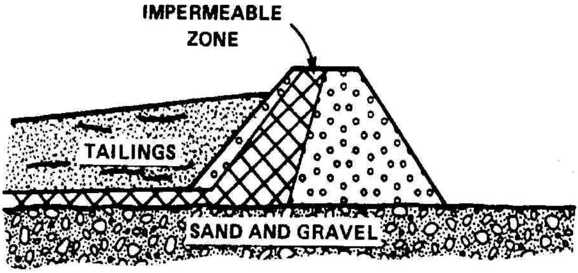
3.4.1.4 Cutoff Walls

Seepage outflow can be minimized by placing impermeable blankets or zones in the embankment or foundations, as illustrated in Figure 3-4A. A cutoff wall of the type shown in Figure 3-4B can be used in cases where a relatively impervious layer underlies a pervious layer at a shallow depth. The impervious core below the embankment will cut off the flow through the shallow, pervious portion of the foundation. A cutoff wall is usually placed toward the upstream portion of the embankment section to allow drained conditions under as much of the embankment section as practicable.[45] However, if total cutoff of seepage is desired (illustrated in Figure 3-4C), the cutoff wall can be installed far downstream, and the seepage can be removed from the drainage trench, pumped back to the impoundment, and then returned to the mill, or it can be pumped to a treatment plant and then released into a natural channel. A small amount of seepage will percolate downward, even through nearly impervious natural materials, from any unlined portion of the waste disposal

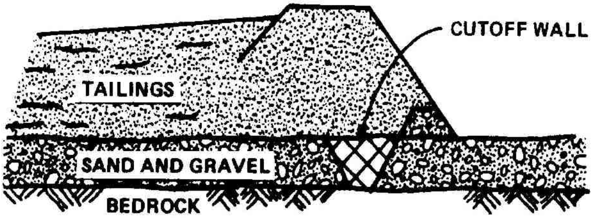


Source: PEDCo Environmental, Inc. 1985

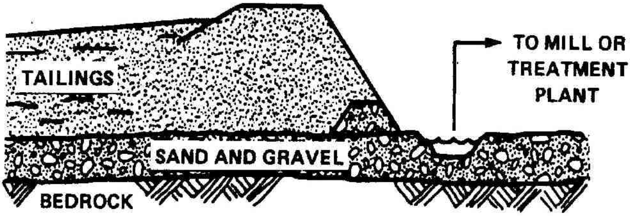
Figure 3-3 Impermeable pad under a gold heap leach pile



A. BLANKET AND CORE METHOD



B. FOUNDATION CUTOFF WALL METHOD



C. CUTOFF WALL AND OPEN TRENCH METHOD

Source: PEDCo Environmental, Inc. 1984

Figure 3-4 Some methods used to minimize seepage outflow area; additional monitoring wells may be required in such cases. When the foundation consists of a thick pervious layer or several pervious layers separated by strata or impervious materials, a drainage trench can be used to remove some of the seepage.

3.4.1.5 Leachate Collection, Removal, and Treatment

During active site life, it is necessary to collect, remove, and treat leachate from lined waste piles to prevent the leachate from building up above the liner. Leachate collection prevents high moisture content at the base of the pile from deforming the structure of the pile. For small lined areas of facilities, an adequate leachate collection system may consist of a sump with a pump to collect the waste and pipe it to a lined impoundment for treatment. In larger facilities, a zone of sand, gravel, or coarse rock may be placed below the waste and drained. Such a system may be augmented by perforated pipe to increase capacity, and may also include collector trenches in cases in which the system emerges onto a broad, level area. Collector trenches may be useful even when no liners are used. Collected leachate must be treated and disposed of by such treatment methods as neutralization and precipitation, as discussed above.

At heap or dump leach operations, secondary leachate collection systems, consisting of leachate collection sumps and ditches, serve to interrupt liquids escaping the primary recirculating leaching system. The extent of adequate secondary leachate collection and removal from heap/dump leach waste and from tailings ponds is shown in Tables 3-8 and 3-9, respectively. Of the gold mines studied by EPA, only one had a secondary leachate collection and removal system in place that was adequate to satisfy current RCRA requirements for such systems. Secondary collection and removal of leachate from tailings

Table 3-8 Extent of Secondary Leachate Collection and Removal from Heap/Dump Leach Waste, by Industry Segment

Mining industry segment	Number of mines in data base that generate heap/dump leach waste	Number of mine sites that collect and remove leachate from heap/dump leach waste[a]	States requiring secondary leachate collection and removal or having mine sites that collect and remove leachate from heap/dump leach waste[b,c]
Copper	9	0	
Gold	5	1 (20%)	New Mexico, Nevada
Silver	2	0	

a Sites are identified as having secondary leachate collection and removal systems only when the system is adequate to satisfy current RCRA requirements.

b This column includes only those states where leachate collection and removal requirements are at least as stringent as those required by RCRA.

c This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

Table 3-9 Extent of Secondary Leachate Collection and Removal from Tailings Ponds, by Industry Segment

Mining industry segment	Number of mines in data base that generate tailings	Number of mines sites that collect and remove leachate from tailings ponds[a]	States requiring secondary leachate collection and removal or having mine sites that collect and remove leachate from tailings ponds[b,c]
Copper	12	0	
Gold	7	2 (29%)	California, South Dakota, Nevada
Lead	6	0	
Phosphate	18	0	
Silver	8	2 (25%)	Montana, Colorado, Idaho, Utah
Zinc	6	0	

a Sites are identified as having secondary leachate collection and removal systems only when the system is adequate to satisfy current RCRA requirements.

b This column includes only those states where leachate collection and removal requirements are at least as stringent as those required by RCRA.

c This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

ponds are practiced only at two gold mine sites studied by EPA, as shown in Table 3-9.

3.4.1.6 Security Measures

During the active site life phase of operations, the mining industry implements security measures that range from posting "No Trespassing" signs to installing comprehensive systems of locked gates and fencing and using security guards. Fencing material ranges from chain link to barbed wire. The extent of the security measures employed depends on the severity of the hazards existing at the mine site, the value of the material being mined or milled, and the proximity of the mine site to populated areas. Posting security guards has an additional benefit, because these employees can also be assigned facility inspection duties, such as checking runoff dikes. At active and inactive asbestos waste disposal sites, existing EPA regulations (40 CFR Part 61) require security measures.

3.4.2 Mitigative Measures at Closure

The mitigative methods described above for the active site life phase remain applicable during the closure phase. In addition, other activities may be necessary or desirable. For example, tailings impoundments may be dewatered and stabilized; these are essential steps if a cap and cover are to be added. A cap and cover can be placed over the site to minimize contact of the waste with the environment and to protect the waste from rainfall, which increases the volume of leachate formed.

3.4.2.1 Wastewater Treatment

The wastewater that remains onsite after active mining and milling operations have ceased may be treated and then discharged or be transported to a licensed disposal site.

3.4.2.2 Wastewater Pond Sediment Removal

The sediment that is collected in wastewater treatment and retention ponds often contains settled solids created during the mining or milling processes, precipitated metals, and process chemicals such as flotation reagents. Assessment of the potential hazards must be made during the active life of the mine and at closure, in order to properly dispose of and manage these wastes. The quality of these sediments varies widely, and some sediments may require removal at closure to reduce potential hazards, while other sediments may pose little or no risk to humans or the environment.

3.4.2.3 Dike Stabilization

A major consideration in the closure of a waste disposal site or area is the structural integrity of the dike(s) constructed to confine the waste.[46,47] Various methods of slope stabilization, such as slope modification and/or placement of waste rock (rip-rap), topsoil, vegetation, and chemical stabilizers, may be used during the active or final closure phases of the life of the impoundment to minimize erosion and siltation.[48] Closure of a diked impoundment may require an assessment of the ability of the dike system to withstand additional loads, which may include the weight of several layers of a capping system (clay, drainage layer, and topsoil cover) and of the construction equipment used to place and compact the final cover.[49] The long-term control of water behind the dike is a major factor in the stability of dikes and prevention of catastrophic failure.

3.4.2.4 Waste Stabilization

Since wastes remain in place after closure of the waste piles and ponds, proper consolidation and stabilization of the wastes are necessary to ensure long-term support for the final cover when it is emplaced. The initial step in stabilizing tailings is dewatering the wastes. At some sites (e.g., copper tailings ponds located in the arid Southwest), passive dewatering using natural evaporation and drainage mechanisms may be sufficient to remove free-standing water and to dewater the tailings. At other sites, active dewatering using pumps to remove liquids within the impoundment or from ponds on the impoundment surface may also be required in conjunction with passive dewatering mechanisms. The liquids collected during dewatering operations may require treatment before they are discharged or disposed of.

The wastes within the impoundment must also be capable of bearing the loadings imposed by the final cover system and the construction equipment used to apply this system. Tests can be used to estimate the anticipated amount of waste settlement and any differential settling across the waste site likely to be caused by increased loads.[50] The results of these tests may indicate the need for further dewatering, for redistribution of the wastes or compaction of the material (e.g., mechanical compaction such as with a sheepfoot roller), or for implementing methods of minimizing differential settlement.

3.4.2.5 Installation of Leachate Collection, Treatment, and Removal Systems for Lined Surface Impoundments

In order for these systems to be effective in collecting leachate, the post-closure needs of the system must be integrated into the initial design of the impoundment.

3.4.2.6 Final Cover System

The proper installation of a final cover system over the exposed surfaces of the waste impoundment, mine waste pile, leach dumps, etc., helps ensure control of erosion, fugitive dust, and surface water infiltration; promotes proper drainage; and creates an area that is aesthetically pleasing and amenable to alternative land uses. This cover system typically consists of the following components:

- A low-permeability clay layer or synthetic membrane overlying the waste material;
- A middle drainage layer of moderate to high permeability;
- A top cover of topsoil and vegetation, except in the arid regions the Western United States, where a rock cover is more effective preventing erosion and breaching. [51,52]

The function of the low permeability material overlying the waste is to prevent the infiltration of precipitation, minimize leachate generation, and prevent the migration of potentially hazardous waste constituents from the waste into the ground water.[53] To prevent excessive leachate buildup, the low permeability layer should be at least as impermeable as the liner, if present.

If the final cover system is to be vegetated, a drainage layer of sand or gravel having low hydraulic conductivity is laid over the impermeable cap. This layer is graded (at least 2 percent) to allow the precipitation infiltrating the vegetative cover to drain rapidly, thus minimizing the hydraulic head on the clay cap or synthetic liner. Then, depending on the gradation, this layer is overlaid by a filter to prevent clogging.

Except in arid regions, the top layer of the cover system consists of topsoil capable of sustaining vegetation. Two feet of soil are considered adequate to accommodate the root systems of most nonwoody vegetative covers and to provide a degree of protection from root damage to the underlying clay or synthetic liner.[54] Wide variance in climatological factors and soil conditions, and therefore in subsequent growing conditions, affects the level of effort required to revegetate mined land successfully. For example, much less work is required at a Florida phosphate mine, where conditions are favorable (fertile soils, adequate water, and long growing seasons) than at a southwestern copper facility, where a combination of poor soils (e.g., high in salts and sulfides, low in nutrients) and an arid climate may require managers to introduce nonnative plant species, install irrigation systems, and provide constant maintenance to develop and sustain the vegetative cover. Revegetation also requires extra effort at sites in mountainous terrain where erosion rates are often high, growing seasons are short, and winters are long and severe.

Tables 3-10 through 3-12 show the number of mine sites studied by EPA where some types of closure activity are performed. Mines in many of the industry segments stabilize their wastes, install some kind of cap, and revegetate during the closure phase. For example, mine waste piles generated by the gold industry in California are contoured for stability and revegetated. For tailings generated by the phosphate industry in North Carolina, reclamation consists of covering the tailings with sand to increase stability, adding topsoil, and revegetating. Similarly, closure of tailings piles at sites in the gold and silver industries in Montana consists of compacting, grading, capping the tailings with rock and topsoil, and revegetating. Although waste stabilization, capping, reclamation, and revegetation appear to be common waste management practices in many industry segments, installing a final cover, consisting of a low-permeability clay layer or a synthetic membrane overlying the waste material, is not a mitigative practice used in the mining industry. [55] However, asbestos waste piles must be covered daily, as required by EPA regulations in 40 CFR Part 61, if there are visible emissions to the outside air.

Table 3-10 Closure Activities for Mine Waste, by Industry Segment

Mining industry segment	Number of mines in data base that generate mine waste	Number of mines performing some types of closure activity	States requiring some types of closure activity or having mine sites that perform some types of closure activity[a]
Gold	6	2 (33%)	California, Colorado
Phosphate	11	11 (100%)	Florida, Idaho
Silver	5	4 (80%)	Idaho, Colorado, Utah
Uranium	6	6 (100%)	Colorado, Wyoming

a This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles Rivers Associates 1984 and 1985c.

Table 3-11 Extent of Closure Activities for Heap/Dump Leach Waste, by Industry Segment

Mining industry segment	Number of mines in data base that generate heap/dump leach waste	Number of mines performing some types of closure activity	States requiring some types of closure activity or having mine sites that perform some types of closure activity[a]
Copper	8	1 (13%)	Utah
Gold	5	0	
Silver	1	0	

a This column includes only the states generating large amounts of mining industry waste in the affected industry segments.

Source: Charles River Associates 1984 and 1985c.

Table 3-12 Closure Activities for Tailings Impoundments, by Industry Segment

Mining industry segment	Number of mines in data base that generate tailings	Number of mines performing some types of closure activity	States requiring some types of closure activity or having mine sites that perform some types of closure activity[a]
Copper	4	1 (25%)	Utah, New Mexico
Gold	7	3 (43%)	South Dakota, California, Arizona, Montana, Nevada
Lead	4	0	
Phosphate	12	12 (100%)	Florida, Idaho, North Carolina
Silver	4	4 (100%)	Idaho, Colorado, Utah Nevada, Montana
Zinc	3	1 (33%)	

a This column includes only the states generating large amounts of mining industry waste in the affected industry sectors.

Source: Charles River Associates 1984 and 1985c.

3.4.3 Mitigative Measures During Post-Closure

At certain sites during the post-closure phase, it is necessary to continue to support the waste management methods applied during the active and closure phases of site life. Many post-closure activities, such as inspection, are routine during active site life but require special effort to maintain once the site has been closed. For example, inspection activities after site closure should be part of a program of regularly scheduled visits.

Inspection and detection activities during the post-closure period may consist of the following:

- Assessment of the density, cover, and composition of vegetation species to evaluate revegetation success;
- Visual or photographic inspection to detect rill and gully erosion;
- Analysis of data on ground-water quality to define contaminant migration and dilution and to determine the effectiveness of liners, cutoff walls, or other containment systems;
- Evaluation of data on ground-water level to define ground-water recovery rates and levels;
- Visual or photographic inspection of stream and drainage channels to determine migration rates and patterns;
- Monitoring of subsidence; and
- Visual and photographic inspection after severe meteorological events (severe precipitation or drought) or other natural phenomena (e.g., earthquakes).[56,57]

Maintenance conducted during the post-closure period may consist of the following:

- Reseeding areas that have not been successfully revegetated;
- Repairing or replacing security fences, gates, locks, and warning signs;
- Maintaining collection and treatment systems;
- Maintaining monitoring wells and replacing them as necessary;

- Replacing rip-rap to control the migration of stream and drainage channels and the effects of flooding;
- Replacing top soil and rock covers to control rill and gully erosion; and
- Eliminating trees and other deep-rooted vegetation that may damage covers and liners.[58,59]

3.4.4 Corrective Action Measures

The corrective action measures described below may be necessary if a plume of contaminated ground water above some threshold limits has been detected. In this phase, the two major activities are additional hydrogeologic evaluation and controlling the plume. These processes are described below. Corrective action measures have not normally been performed at mining facilities in the past.

3.4.4.1 Hydrogeological Evaluation

Once ground-water contamination has been detected by the ground-water monitoring system, an extensive hydrogeological evaluation is usually needed to determine the size, depth, and rate of flow of the contaminated plume. The methods and limitations of hydrogeological evaluations in the corrective action stage are similar to those that apply to these evaluations during active site life.

3.4.4.2 Interceptor Wells

Seepage losses through the deep pervious foundation of a waste disposal facility can be reduced by installing interceptor wells at points that intersect the plumes of contaminated seepage in the saturated zone. [60] Comprehensive hydrogeological explorations and evaluations are required to site these wells properly. The intercepted seepage may be pumped directly to a mill or pond if water balances permit, or it may be treated before being returned to the mill or discharged.

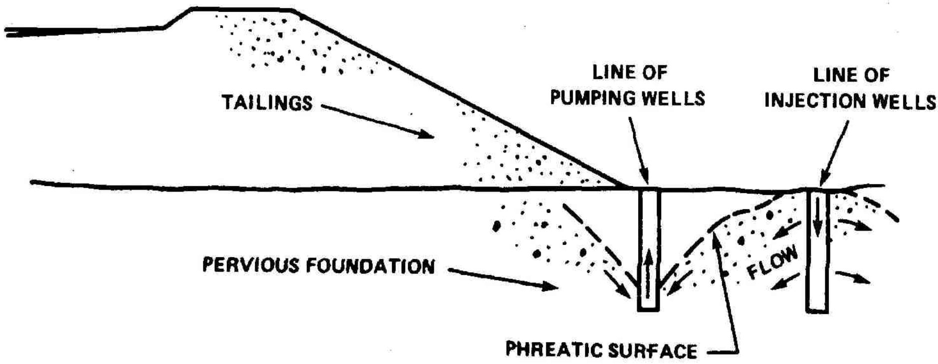
3.4.4.3 Hydraulic Barriers

Interceptor wells may be used in combination with a hydraulic barrier system establis downgradient to the embankment, as shown in Figure 3-5. A hydraulic barrier system is made by installing a line of pumping wells downgradient to the leaking embankment, ar injection wells downgradient to the pumping wells. The injection wells supply fresh wa the pumping wells extract ground water. Pump effluent is typically a mixture of native water, plume water, and injected fresh water. The use of hydraulic barriers is effective a where the subsurface is generally homogeneous. The use of hydraulic barriers is not a practice in these segments, and their effectiveness must be demonstrated.

3.4.4.4 Grouting

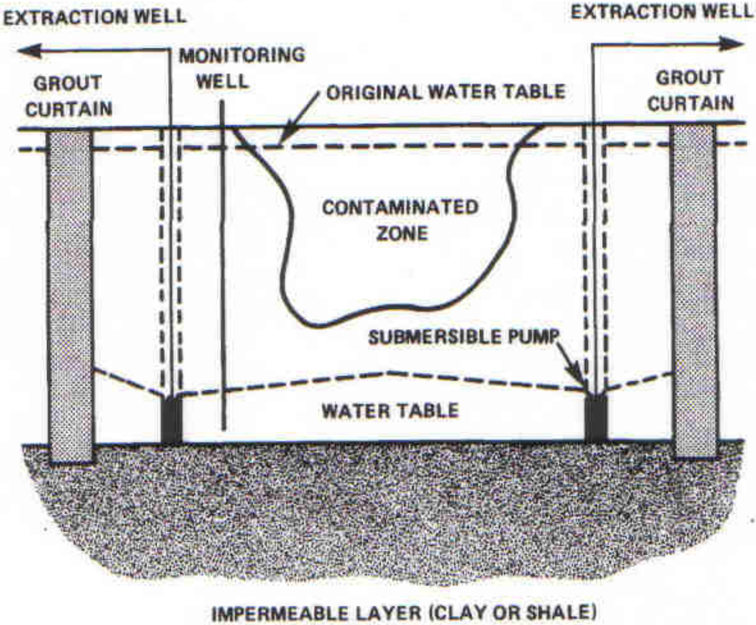
If a waste presents a serious pollution hazard to ground water, grouting the foundati may be warranted. The grouting process consists of pumping a fluid grout mixture (usu water-cement compound) through drill holes into crevices and joints in rock to tighten t embankment foundation. Chemical grout is used to seal porous materials and cracks th small to accept a water-cement grout. Grouting must be thorough, because even a few joints in permeable rock formations can render the grouting effort ineffective.[61]

Figure 3-6 illustrates a grout curtain being used in conjunction with extraction wells. grouting process is often not very reliable, because it is difficult to ensure a completely impermeable grout curtain. Generally, grout curtains cannot be used to control deep ver seepage within the curtain's boundaries. In some cases, grout curtains can reach depths meters; however, both the cost and unreliability of these systems increase rapidly at depths greater than 30 meters.[62]



Source: PEDCo Environmental, Inc. 1984

Figure 3-5 Hydraulic barrier for seepage collection



Source: PEDCo Environmental, Inc. 1984

Figure 3-6 Grout curtains and extraction wells for seepage control

3.4.4.5 Cutoff Walls

Cutoff walls are often used as seepage or ground-water pollution control systems be are effective and relatively inexpensive. Sheet piling cutoff walls can extend 24-30 mete but they have a relatively short effective life (less than 20 years) and are difficult to cons achieve a low permeability barrier. More effective cutoff walls can be constructed by di narrow trenches to a depth of 9-15 meters and backfilling them, either with a soil-bento soil-cement-bentonite mixture that hardens into a homogeneous and very low-permeab The effective use of cutoff walls is highly dependent on the site's hydrogeologic properti naturally impermeable rock and/or soil must underlie the waste within the cost-effective depth. If an impermeable layer does not exist, cutoff walls will be ineffective in stopping of pollutants. This technology is not applicable to all mines, and is not a common pract industry.

3.5 SUMMARY

Of the waste currently generated by the mining industry segments of concern, 56 pe disposed of on site, 9 percent is backfilled, 31 percent may be considered to be utilized (principally in the leaching of copper dump wastes and in starter dams for tailings impo and 4 percent is utilized off site (as fill and aggregate for road construction). Most tailin disposed of in impoundments; but 5 percent are backfilled, and 2 percent are used off s construction, as soil supplements, etc.). Most mine water is recycled through the mill a site for other purposes (e.g., dust control) or treated and discharged. Few

methods are available to reduce the amount of solid waste generated by mining and mi
process modifications can reduce the water content and potential toxicity of these wast
methods are available to design, site, maintain, and close disposal facilities in an enviro
acceptable manner. Commonly used mitigative measures include ground-water monito
leach operations only; and, for many types of operations, stabilization of waste, installa
some kind of cap, and revegetation during the closure phase. Available corrective action
not widely used in the mining industry, include interceptor wells, underground barriers
the spread of contaminated ground water, and liners to contain the leachate.

SECTION 3 FOOTNOTES

1 Tailings are often disposed of in ponds because, as described in Section 2, they leave the mill as a slurry.

2. Greber et al. 1979.

3 Charles River Associates 1985a.

4 Vick 1981.

5 Goodson and Associates 1982.

6 Curtin 1983.

7 Seitter and Hunt 1982.

8 Seitter and Hunt 1982.

9 Seitter and Hunt 1982.

10 Charles River Associates 1985b.

11 Schiller 1983.

12 Heming 1984.

13 PEDCo Environmental, Inc. 1984.

14 USDA Forest Service 1979.

15 PEDCo Environmental, Inc. 1984.

16 Wixson et al. 1983.

17 Seitter and Hunt 1982.

18 A stope is an excavation from which ore has been mined in a series of steps.

19 Vick 1981.

20 Vick 1981.

21 Goodson and Associates 1982.

22 Klohn 1981.

SECTION 3 FOOTNOTES (Continued)

23 Portfors 1981.

24 Vick 1981.

25 US EPA 1982a.

26 Vick 1981.

27 EPA 1982a.

28 Vick 1981.

29 PEDCo Environmental, Inc. 1984.

30 Goodson and Associates 1982.

31 PEDCo Environmental, Inc. 1984.

32 TFI 1984.

33 U.S. Nuclear Regulatory Commission 1983

34 BOM 1985.

35 Geological Society of America 1971.

36 U.S. Nuclear Regulatory Commission 1983.

37 New Mexico Energy and Mining Department 1979.

38 New Mexico Energy and Mining Department 1979.

39 Pacific Northwest Laboratories 1983.

40 BOM 1980b.

41 Lucia 1982.

42 Edwards et al. 1983.

43 DOE 1985.

44 DOE 1985.

45 BOM 1980.

46 U.S. Nuclear Regulatory Commission 1983.

SECTION 3 FOOTNOTES (Continued)

47 Lucia 1982.

48 DOE 1985.

49 DOE 1985.

50 DOE 1985.

51 DOE 1985.

52 U.S. Nuclear Regulatory Commission 1983.

53 DOE 1985.

54 DOE 1985.

55 Charles River Associates 1984.

56 DOE 1985.

57 U.S. Nuclear Regulatory Commission 1983.

58 DOE 1985.

59 U.S. Nuclear Regulatory Commission 1983.

60 BOM 1985.

61 BOM 1980b.

62 Greber et al. 1979.